RC2: 'Review', Anonymous Referee #2, 05 Apr 2018

The paper investigates the relationship between estuary planform shape and along-channel variations in hypsometry. The authors recall the definition of "ideal estuary" and assume that along-channel changes in hypsometry (e.g. changes from concave to convex hypsometry) depend on the deviation of estuarine cross-sectional width from the "ideal width" dictated by an exponentially decreasing function. The paper builds upon previous findings by the authors (Leuven et al., 2016, 2017) showing that "excess width" (with respect to the ideal width) allows one to predict the location of tidal bars within the estuary. The new finding is that concave hypsometry occurs where no bars are observed and the estuary width is close to the ideal one, whereas convex hypsometry occurs where extensive bars develop at a given location (or cross section) and estuary width is much larger than the ideal one. The paper is well written and clearly organized. It addresses a relevant issue of practical importance, particularly in view of current anthropogenic influence on estuarine morphology and dynamics. As such, it deserves credit and it will be of interest to the readership of ESurf. I have a few minor suggestions made in the effort to improve an already good paper.

We found the review helpful and positive and thank the reviewer in the acknowledgements. Below we describe (in italics) how we used the reviewer comments to improve the manuscript.

General Comments

The authors use the "ideal estuary" model that is based on a set of assumptions. The authors then discuss their results by relating them to the ratio between the observed estuary width and the "ideal" width obtained by considering an exponential width variation along the estuary. As noted, the "ideal estuary" model embeds a set of assumptions that should be discussed more in detail. As an example, the authors compare "ideal" and observed widths, but then assume a linear landward decrease in channel depth, whereas the ideal model prescribes a different behavior.

This comment relates to the third comment of reviewer 1. We now added a new section at the start of the methods section in which we discuss the assumptions of the ideal estuary in more detail, including explanation how this lead to our geometric approach and that it shouldn't be confused with the "ideal" state:

"A useful model to describe the morphology of estuaries is that of the 'ideal estuary'. In an ideal estuary the energy per unit width remains constant along estuarine channels. This ideal state can be met when tidal range and tidal current are constant along-channel, such that the loss of tidal energy by friction is balanced by the gain in tidal energy per unit width by channel convergence (Pillsbury, 1956; Dronkers, 2017). In case the depth is constant along the channel, the ideal estuary conditions are approximately met when the width is exponentially decreasing in landward direction (Pillsbury, 1956; Langbein, 1963; Savenije, 2006; Toffolon & Crosato, 2010; Savenije, 2015), which also implies an along-channel converging cross-sectional area. However, when depth and friction are not constant along-channel, but for example linearly decreasing in landward direction, less convergence in width is required to maintain constant energy per unit of width. Many natural estuaries are neither in equilibrium nor in a condition of constant tidal energy per unit width. They deviate from the ideal ones as result of varying degree of sediment supply, lack of time for adaptation to changing upstream conditions and sea-level rise (Townend, 2012; de Haas et al., 2017). Whether continued sedimentation would reform bar-built estuaries into proper ideal estuaries remains an open question. For our application, the concept of ideal estuaries is useful to assess the degree of deviation from ideal because of the width variations observed as bars, tidal flats and saltmarsh. While we expect a somewhat different degree of convergence such that the ideal state of constant energy per unit of width is approximately maintained, we do not study the deviation of this convergence length from that in ideal estuaries.

Ideally, we would want to assess the degree to which an estuary is in equilibrium from an aerial photograph, because this is often the only data available. However, the only indicator derivable from aerial photography is channel width and thus deviation from a converging width profile. Therefore, in

Leuven et al. (2017), we defined the excess width, which is the local width of the estuary minus our approximation of the potential ideal estuary width. Here, the ideal estuary width is approximated as an exponential fit on the width of the mouth and the width of the landward river. While the empirical measure of 'ideal width' should not be confused with the 'ideal state' of an estuary, it is the only practical way to estimate deviation from an ideal estuary based on the estuary outline only. Moreover, it proved to be a good indicator of occurring bar patterns (Leuven et al., 2017) and will therefore be applied in this paper to study hypsometries."

It should be noted here as well that a linear along-channel depth profile can also be a horizontal bed profile in the case that the predicted channel depth based on hydraulic geometry at the landward side and the predicted depth at the mouth based on tidal prism-CSA relations is equal. We clarified this in the text: "Width-averaged depth profiles along estuaries are often (near-) linear (Savenije, 2015; Leuven et al., 2017), which includes horizontal profiles with constant depth."

As to the use of hypsometry, it should be better clarified, from the very beginning, that the theoretical framework is quite different from the one proposed for river basins (Strahler, 1952) and for tidal basins (Boon and Byrne, 1981) because in this case the hypsometric curve is applied across channel width (it is a cross-sectional hypsometric curve). I find the idea clever and interesting, but I'd like to see some more discussion on the reasons leading the authors to set up such an analysis. In addition, in the case of the river and tidal basin, the morphological evolution was accounted for, suggesting that different shapes of the hypsometric curve were associated to young or old systems. Is there any possibility of making such an analogy within the framework proposed by the authors? Can the framework account for the dynamic nature of estuarine landscapes? I also wonder if the framework could be applied to any type of estuary of if there are some limitations. Can micro- and macrotidal systems behave in a different way?
We now clarified that our approach is different from classical hypsometry studies in the first paragraph of the section about the general hypsometric curve: "(…) While it is of interest to use these empirical relations to predict the occurring altitude variation of a landform, the framework here is different, because in this case the hypsometric curve is applied across channel width: it is a cross-sectional hypsometric curve that we change along the system. We aim to use the general hypsometric curve to characterise the occurring cross-sectional hypsometry, (…)".
We added a paragraph in the discussion about need for a physically based determination of the hypsometry, and the lack of theory available to do so, also suggested by reviewer 1. A more physics based theory for hypsometry would be required to answer the open questions proposed by the reviewer.

Finally, I remembered of a paper proposing quite a similar analysis (Toffolon and Crosato, JCR 2017). I think the paper would benefit from recalling the results of the above paper (analyses were applied to the Scheldt estuary). In that paper, the authors analyzed the case of U-shaped, V-shaped, Y-shaped cross section. This could be done also within this framework, to predict the tendency of the estuary to develop particular shapes.
We were aware of this paper but showed in our earlier work that their application of bar theory is flawed. Indeed, they used a similar fitting approach as we did, but (1) used a power function instead of the Strahler formulation and (2) fitted hypsometric profiles for 15 zones along the estuary and characterise their shape. The effect is that they completely smooth out all differences between bars and channel zones which is precisely the point of our paper. Their U-shaped profiles correspond to our concave profiles, Y-shaped to our convex and V-shaped is exactly intermediate. We added references to their methodology in the introduction and methods section of our paper and compare the results of both studies in the discussion.
*<u>Introduction:</u> "Furthermore, hypsometry was used as a data reduction method **to characterise entire reaches spanning bars and channels in estuaries (Toffolon & Crosato, 2007} and** shapes of individual tidal bar tops (de Vet et al., 2017)."*

Methods: *"While it is of interest to use these empirical relations to predict the occurring altitude variation of a landform, the framework here is different, because in this case the hypsometric curve is applied across channel width: it is a cross-sectional hypsometric curve that we change along the system. We aim to use the general hypsometric curve to characterise the occurring cross-sectional hypsometry, which is similar to the approach of Toffolon & Crosato (2007) who fitted a power function to 15 zones along the Western Scheldt. However, the zoned approach smooths out all differences between bar complex and channel-dominated zones, which are of interest for this study."*
Discussion: *"These findings are consistent with hypsometry zonations previously found for the Western Scheldt with more concave hypsometries in for channel-dominated morphology and more convex hypsometries for bar complex morphology (Toffolon & Crosato, 2007). Our cross-sectional approach additionally revealed quasi-periodic behaviour within these zones."*

Detailed comments
Detailed textual comments were mostly incorporated and sometimes used as indicator where text clarity had to be improved. We attach a PDF that highlights the changes to the first submission.